ADAPTATION TO HYPOXIA AS A MEANS OF INCREASING HUMAN RESISTANCE TO RADIAL ACCELERATION

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Among the measures increasing human resistance to overloads an important place is held by physiological methods increasing the reserve powers of the body. These include preliminary physical training, training on a centrifuge, administration of drugs, etc. The specific method of increasing resistance (training on a centrifuge) should probably be used with care, because observations have been reported indicating the development of prolonged functional disturbances and morphological changes under the influence of radial accelerations [3, 6-9, 13].

At the present time researchers are showing great interest in methods of physical training and adaptation to hypoxia as a means of increasing bodily resistance to the action of various injurious external environmental factors [1, 5, 11, 12, 16, 17].

Assuming that hypoxia plays a leading role in the pathogenesis of the disturbances developing during the action of overloading, in conjunction with V. P. Dudarev [4] we carried out experiments on animals to study the effect of adaptation to a lowered partial pressure of oxygen and of muscle training on their resistance to overloads. These experiments showed that adapted albino mice and rats and guinea pigs have much greater resistance than control animals. /289
The results of these experiments justified moving on to investigations on man.

The object of the present investigation was to study the effect of repeated and primary acclimatization in the mountains on the level of tolerance to radial acceleration and also to examine the features distinguishing nonspecific adaptation processes.

Investigations were conducted on 15 subjects, 7 of whom were mountaineers with more than 10 years of experience of the sport. All subjects lived in high mountain conditions at altitudes of between 2-3 and 4-7 km in succession in the region of Mt. El'brus, and two mountaineers lived in the Tyan' Shan' mountains.

The length of stay in the mountains varied from 35 to 41 days for the mountaineers and from 33 to 35 days for the persons adapted for the first time.

The limit of tolerance to radial acceleration was determined by rotation on a centrifuge with an arm radius 7.5 m. The gradient of increase of acceleration was 0.1 g/sec up to 4 g, and 0.2 g/sec thereafter; the angle of inclination of the back of the armchair was 65° to the acceleration vector.

The criterion of limit of tolerance which was most frequently used was the appearance of visual disturbances in the form of a "black" or "gray veil," and less commonly, of disturbances of the circulatory or respiratory indices. Each subject's resistance to acceleration was measured not less than 1-2 weeks before acclimatization and 10-15 days and 1.5-3 months after a stay in the mountains.

The following tests were used to assess the physiological responses to acceleration: the ECG was recorded in three leads by Nebb's method, the arterial pressure measured in the vessels of the arm and ear, and the respiration rate and volume recorded [15]; the time of the motor response to a photic stimulus was determined; the visual acuity was measured.

Two-way radio communication was maintained during the experiments and continuous visual observation of the subject was undertaken by television The results of the investigations showed that the maximal acceleration tolerated by unadapted persons in the control tests was 0.8 g less than that tolerated by the mountaineers.

After a stay of 33-40 days under high mountain conditions both the mountaineers and the unadapted persons showed a significant increase in resistance to acceleration (Table). Tolerance was increased in all the mountaineers without exception, on the average by 1.7 units (within a range of 0.6 to 2.8 units).

The changes in resistance of the subjects adapted for the first time to acceleration showed greater individual scatter. /290

TABLE. Mean Values of Maximal Tolerated Accelerations Before and After Acclimatization in the Mountains

Groups of subjects	Number of cases	Mean values of maximal tolerated accelerations, g			$P <$
		Before acclimitization	After acclimitization	Difference	
Mountaineers	7	10.3±1.4	12.0±1.1	+1.7±0.6	0.001
Subjects adapted for the first time	8	9.6±0.7	11.2±1.3	+1.6±1.4	0.05
	6	9.4±0.6*	11.6±1.0*	+2.2±1.0	0.01

Sampling Mean for Subjects Adapted for the First Time and Showing an Increase in Resistance to Accelerations.

The increase in resistance to acceleration after adaptation under high mountain conditions is also confirmed by changes in some physiological indices especially those characterizing visual function. The threshold of the "gray

veil" was raised by 1.9±0.7 g in the mountaineers and by 2.6±0.8 g in the unacclimatized subjects after a stay in the mountains. Only in two cases was the threshold of appearance of visual disturbances slightly lowered after acclimatization (Fig. 1). In addition, after adaptation to hypoxia, in 10 of 14 cases a higher visual acuity was found than in control subjects exposed to accelerations of identical magnitude.

Nonspecific adaptation processes can be assessed by analyzing changes in certain physiological responses to acceleration before and after adaptation to hypoxia. The mean pulse rate during control rotation at radial accelerations of 8 g was 132±14 beats/min for the mountaineers and 118±14 beats/min for subjects adapted for the first time.

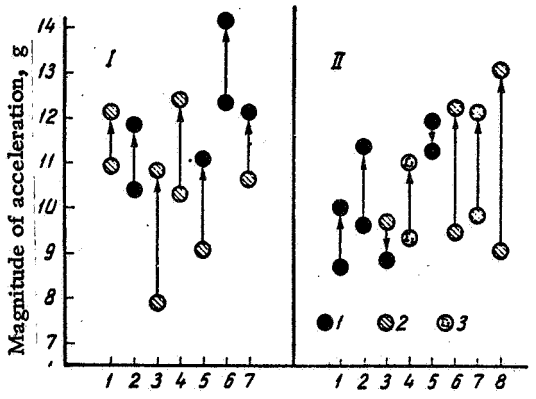

Figure 1. Change in Level of Tolerance and in Severity of Visual Disturbances in (I) Mountaineers and (II) Persons adapted for the First Time After a Stay in the High Mountains. 1) Black Veil, 2) Gray Veil, 3) Extrasystoles.

After acclimatization in the mountains in most cases a more marked tachycardia was observed at accelerations of the same magnitude. The difference in pulse rate for all subjects averaged +12±12 beats/min ($P < 0.05$). In four cases, however, opposite relationships were observed: the increase in pulse rate was less after acclimatization.

Comparison of the indices of external respiration corresponding to identical magnitudes of acceleration showed that the respiration rate remained at about the same level during acceleration of the centrifuge after the subjects had returned from their stay in the mountains as in the control test. The mean difference in the respiration rate was 1-2 cycles (within the range of -4 and +8 cycles/min). The changes in pulmonary ventilation and gas exchange were typical in character of exposure to the action of radial acceleration. After mountain acclimatization, the pulmonary ventilation in most cases, and the oxygen consumption in every case, were at a higher level during acceleration of the centrifuge than in the control tests. /291

In the braking period and immediately after stopping the centrifuge signs of stimulation of respiration were observed, as a result of the oxygen deficit arising during exposure to acceleration. After adaptation to hypoxia, the severity of these changes varied from one individual to another. Despite the considerable magnitude of the overloading reached during braking, in half of the cases the oxygen consumption was practically indistinguishable from the background level or was actually slightly below it. In most cases the oxygen debt was smaller after adaptation than after the background test. Even in cases when no increase in tolerance to overloading took place (2 subjects), the oxygen consumption and oxygen debt during braking and after stopping the centrifuge were

lower than in the first test, demonstrating an increase in the body's reserve powers after adaptation in hypoxia. The respiratory quotient remained higher after adaptation in the mountains than in the control rotations (Fig. 2). The simultaneous increase in the oxygen consumption and respiratory quotient could evidently be attributed to the increased powers of the body to maintain oxygen utilization at a higher level.

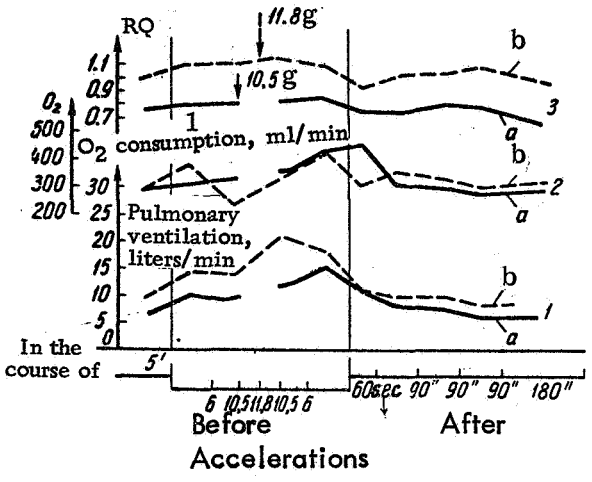

Figure 2. Changes in Pulmonary Ventilation (1), Oxygen Consumption (2) and Respiratory Quotient (3) in the Mountaineer S-t During Exposure to Accelerations before (a) and After (b) a Stay in the High Mountains. Total Duration of Spinning 510 sec.

It may be concluded from the results described above that a short stay under high mountain conditions is an effective and reliable method of increasing human resistance to accelerations. By comparing certain physiological responses preliminary views can be expressed on the possible mechanisms of this adaptation. The strengthening of activity of the cardiovascular and respiratory systems and the response to overloading should probably be regarded as an /292 adaptive response of the human body connected with increased utilization of oxygen in the tissues. On the other hand, another possible cause cannot be ignored: an increase in the resistance to the blood flow because of a possible increase in the viscosity of the blood after a stay under hypoxic conditions. We made no direct measurements of the blood viscosity of our subjects. However, cases of an increase in the blood viscosity of animals in the course of acclimatization to high altitudes have been described in the literature [14].

The results thus demonstrate the need for a further study of the mechanisms of nonspecific adaptation as applied to the problem of human resistance to the action of overloads.

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